UPDATE ON SUPERSONIC JET NOISE RESEARCH AT NASA

An update on jet noise research conducted in the Fundamental Aeronautics and Integrated Systems Research Programs was presented. Highlighted research projects included those focused on the development of prediction tools, diagnostic tools, and noise reduction concepts.

Update on Supersonic Jet Noise Research at NASA

Brenda Henderson
NASA

TETS 2010
September 13 - 16
Dayton, OH

NASA Aeronautics Program

- Fundamental Aeronautics Program
  - Subsonic Rotary Wing (SRW)
  - Hypersonics (HYP)
  - Subsonic Fixed Wing (SFW)
  - Supersonics (SUP)
    - **Airport Noise (AN)**
    - High Altitude Emissions (HAE)
    - Flight Research & Validation (FRV)
    - Supersonic Cruise Efficiency – Propulsion (SCE-P)
    - Supersonic Cruise Efficiency –Airframe (SCE-A)
    - Sonic Boom Modeling (SBM)
    - System Integration & Assessment (SIA)
    - Aero-Propulso-Servo-Elasticity (APSE)
    - Lightweight Durable Engines (LDE)
    - Lightweight Durable Airframe (LDA)
- Integrated Systems Research Program
  - Environmentally Responsible Aviation (ERA)
- Other Aero Programs …

Jet Noise Research

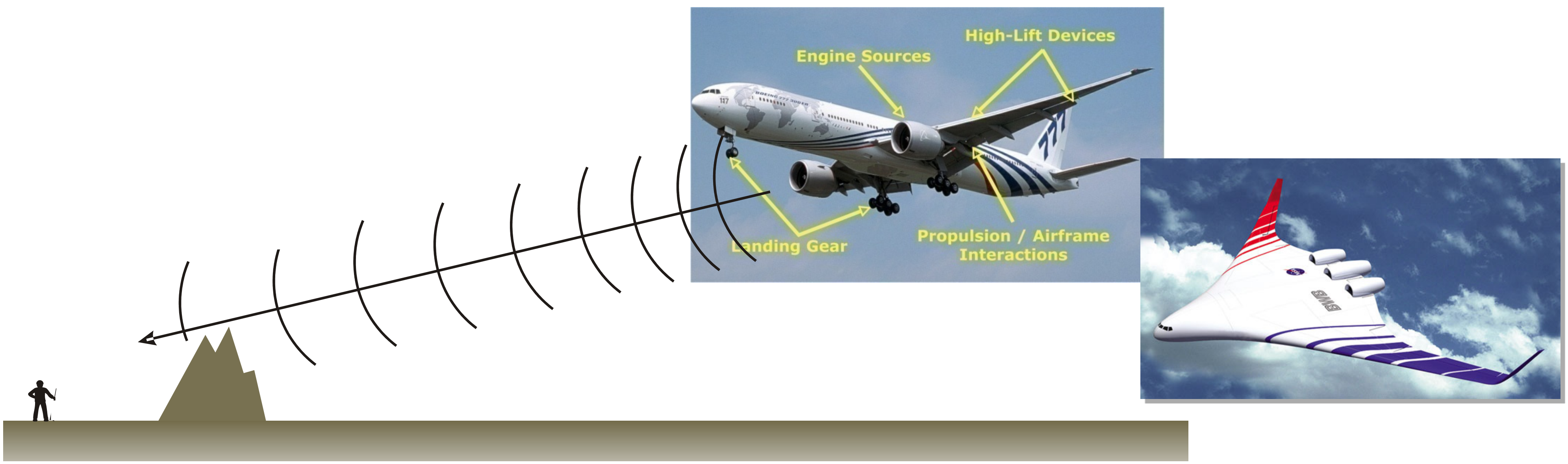
- Prediction Tools
- Diagnostics
- Reduction Concepts

Prediction Tools

NASA Aircraft Noise Prediction Program: ANOPP2

Casey Burley: casey.l.burley@nasa.gov

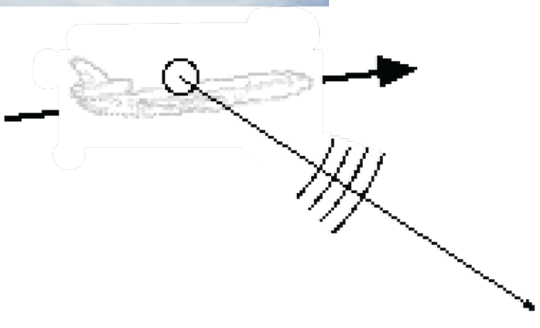
- **Total aircraft noise prediction capability for subsonic and supersonic aircraft.**
  - Predicts Aircraft source noise, propagation and impact at receiver
  - ANOPP2: mixed-fidelity prediction capability
- **Current Emphasis in NASA:**
  - ANOPP2: Mixed-fidelity noise tools to enable system-level trades of noise against other performance parameters for conventional and unconventional aircraft.
- **Specific Capabilities for Supersonic Aircraft Applications**
  - Comprehensive ability to predict high speed jet mixing & broadband shock noise
  - Methodologies for mixer-ejector configurations



Receiver ← Propagation ← Source

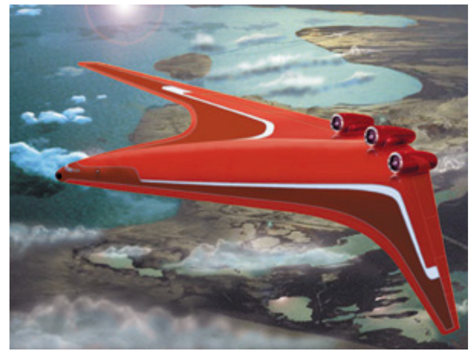
Aircraft System Noise Paradigm

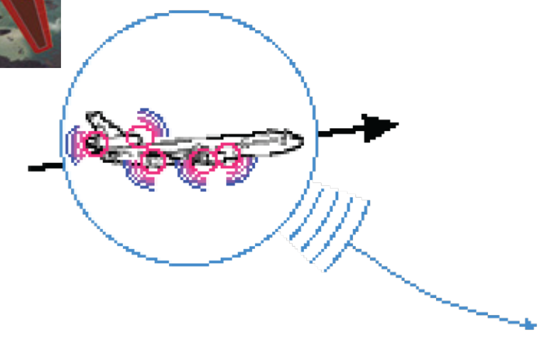
ANOPP (Current Generation)



- All sources at a single point
- Installation effects are estimated
- Effects of atmosphere are primitive
- Cannot extend outside experience
- Empirical and “fixed” fidelity

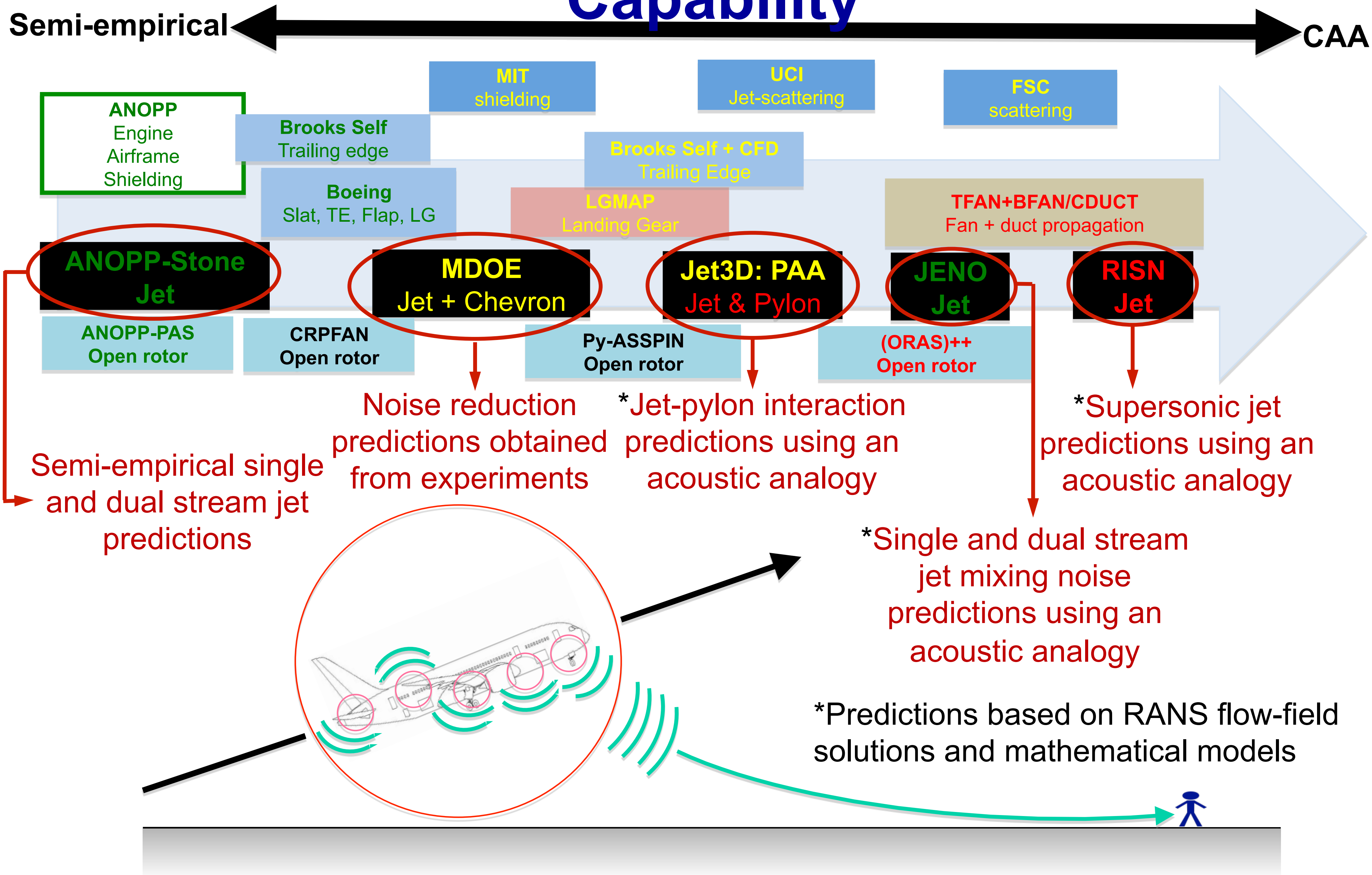
ANOPP2 (Next Generation)





- Noise sources are at their true locations.
- Installation effects included
- Include effects of atmosphere and terrain
- Must predict outside of experience base
- First-principles based & multi-fidelity
- Compatible with MDAO framework

ANOPP2: Mixed-Fidelity System Noise Capability

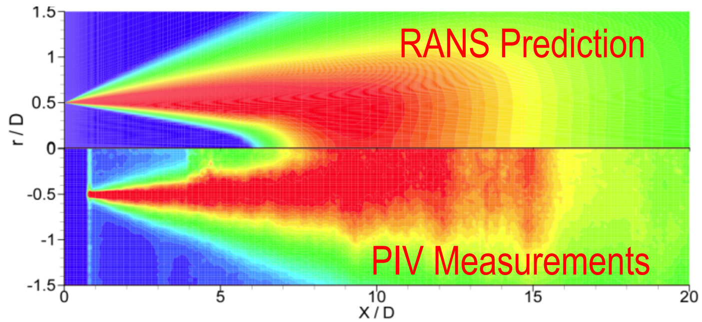


JeNo—RANS-based Jet Noise Prediction

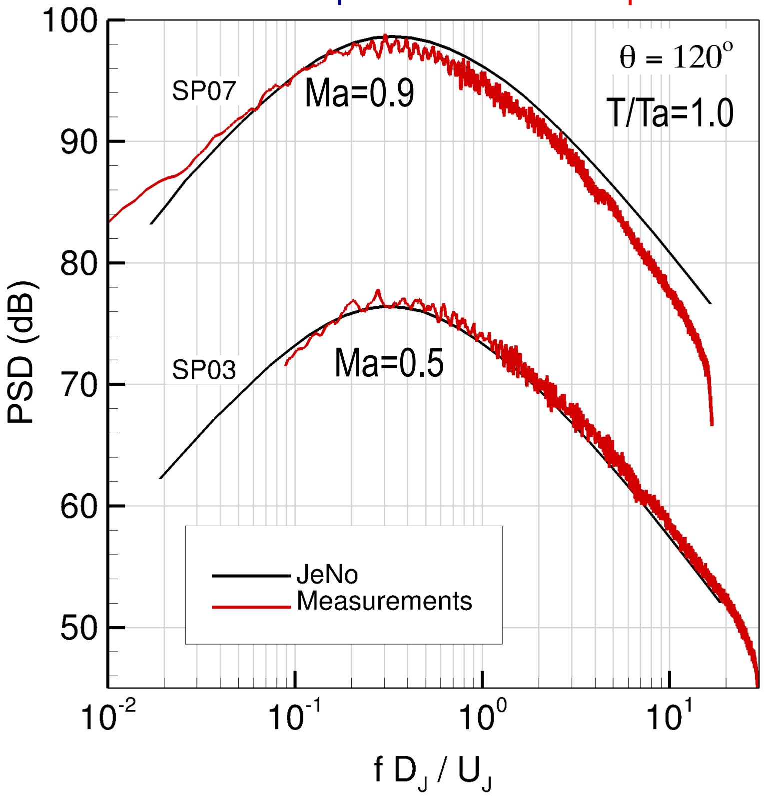
Abbas Khavaran: abbas.khavaran-1@nasa.gov

Cold Subsonic Jets

Turbulent Kinetic Energy

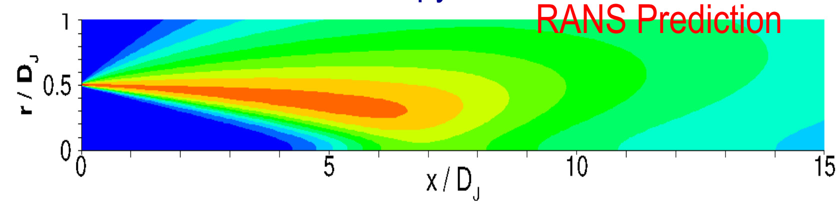


Noise Spectra—JeNo vs Expt

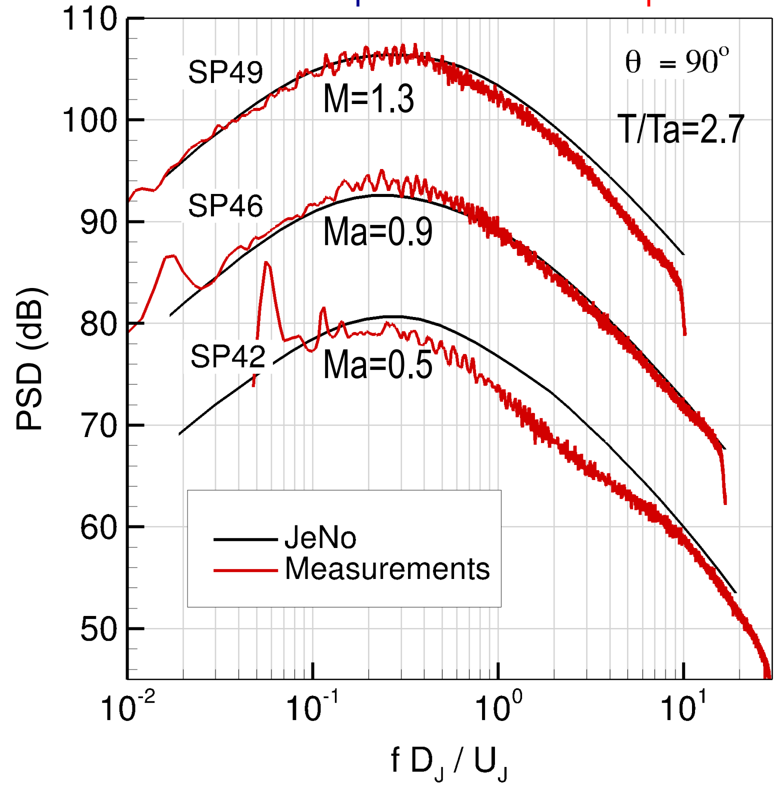


Hot Subsonic Jets

Turbulent Enthalpy as Additional Source



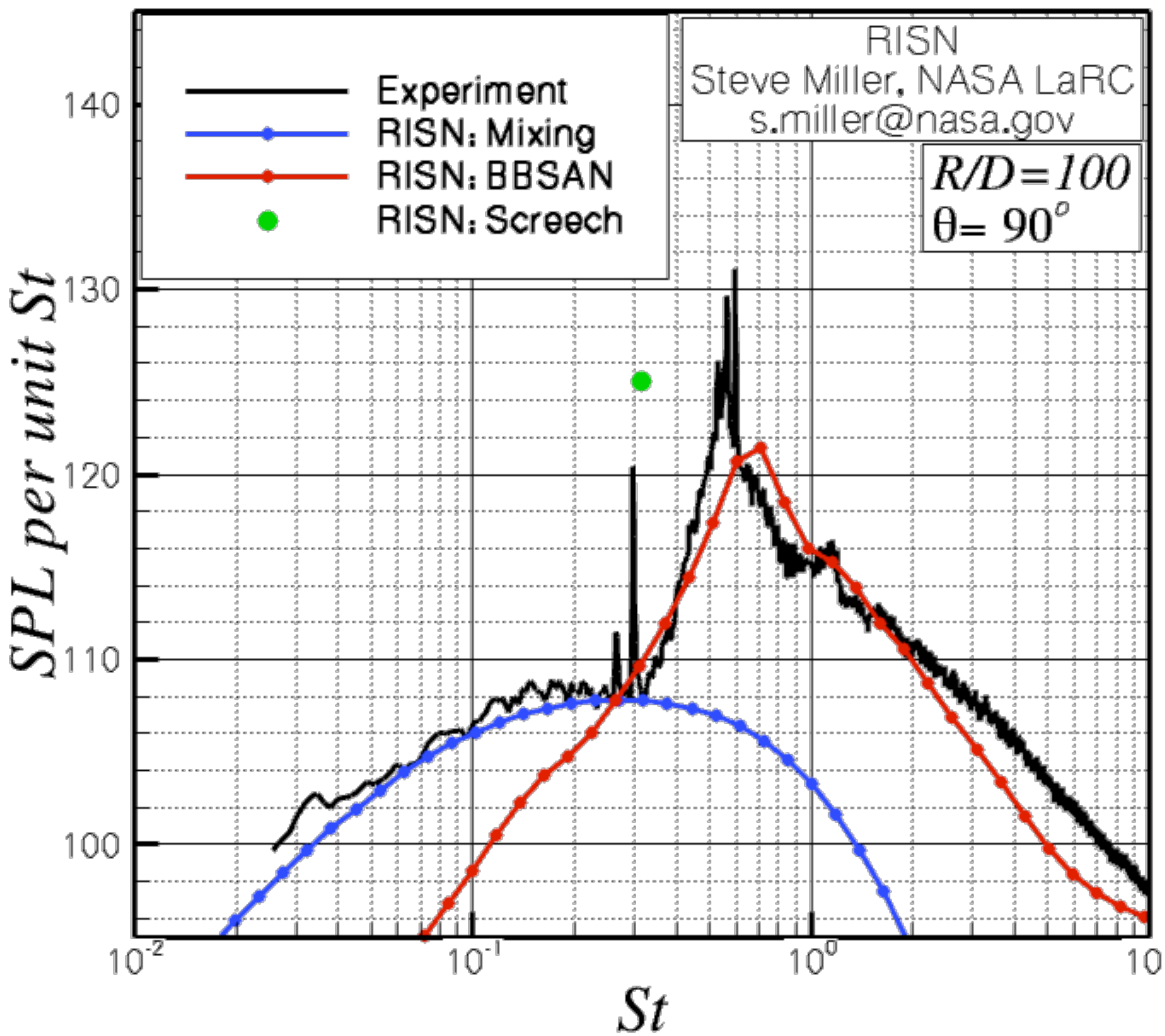
Noise Spectra—JeNo vs Expt



RISN: RANS Integration for Shock Noise

Steve Miller: s.miller@nasa.gov

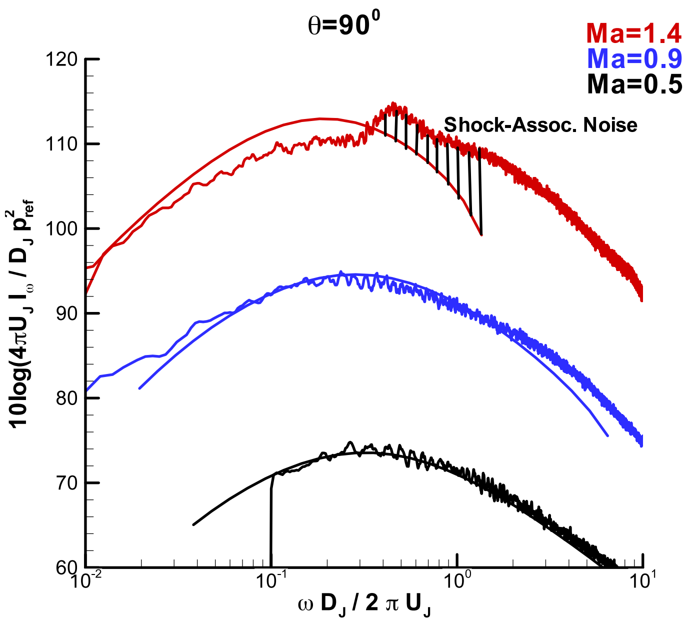
- *Comprehensive* model for supersonic jet noise
  - Axi/3D Flows
  - Shock Noise (BBSAN)
- Under development
  - Improved Broadband shock noise
  - Mixing noise
  - Screech
- Future planned capabilities
  - Mach wave radiation predictions
  - Improved handling of refraction
  - Integrated gridless CFD solutions

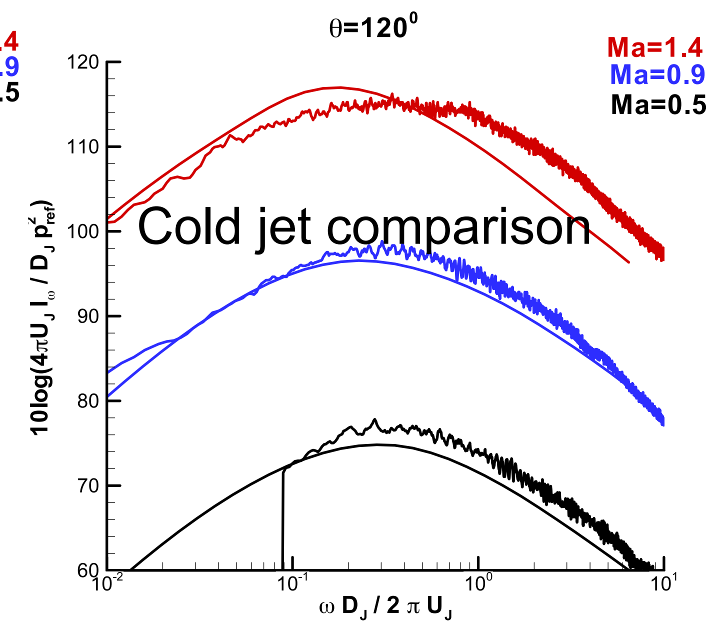


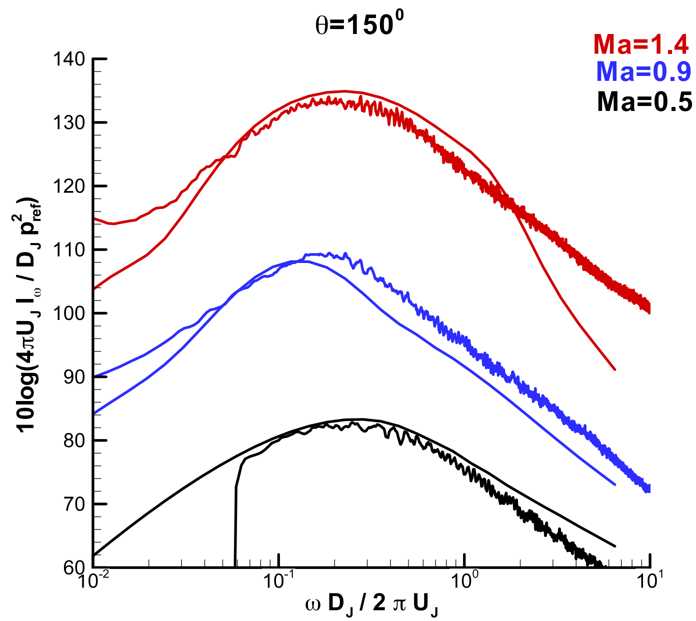
Goldstein Generalized Acoustic Analogy

Stewart Leib: stewart.j.leib@nasa.gov

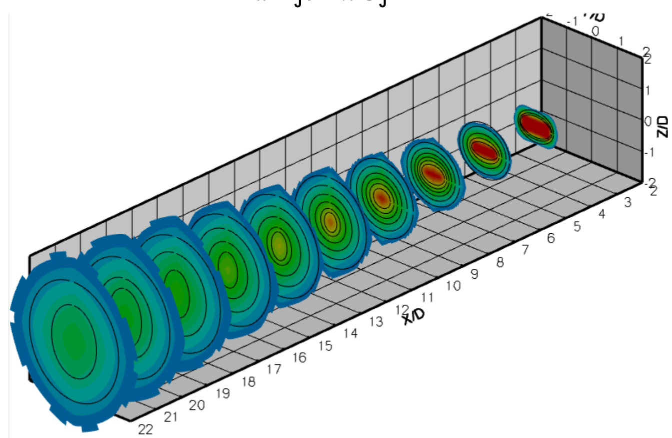
- Prediction code for mixing noise from subsonic and supersonic round jets
- A hybrid (time/frequency domain) source model has been implemented
- Accurate representation of the Reynolds stress auto covariance tensor (source terms)

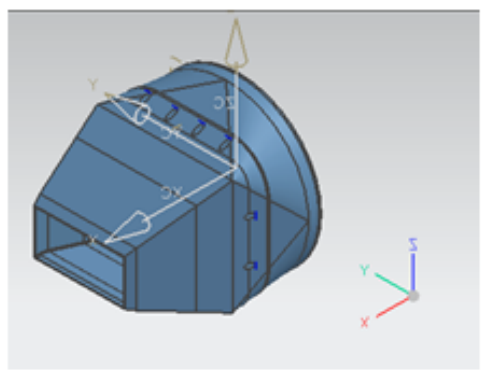






- Improving extension to non-circular jets



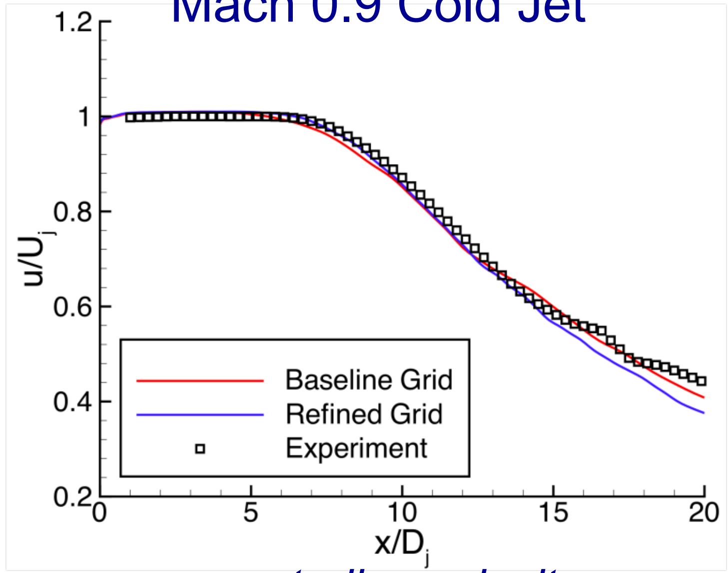


Large-Eddy Simulation Research

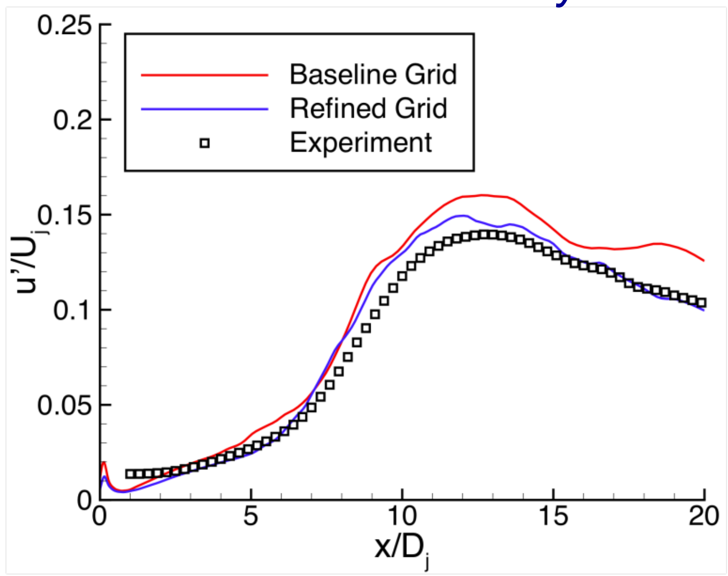
Jim Debonis: james.r.debonis@nasa.gov

- Developing a high-order large-eddy simulation capability for supersonic jets
- Working with aerospace community to develop a “best practices” for LES (AIAA and ERCOFTAC)
- WRLES Code
  - Blocked structured grid in generalized curvilinear coordinates
  - Low dispersion Runge-Kutta time stepping, 1^{st} – 4^{th} order
  - Spatial discretization
    - Standard schemes 2^{nd} – 12^{th} order
    - DRP schemes 7 – 13 point
  - Shock capturing filters
  - Hybrid MPI/OpenMP parallel

Mach 0.9 Cold Jet



centerline velocity



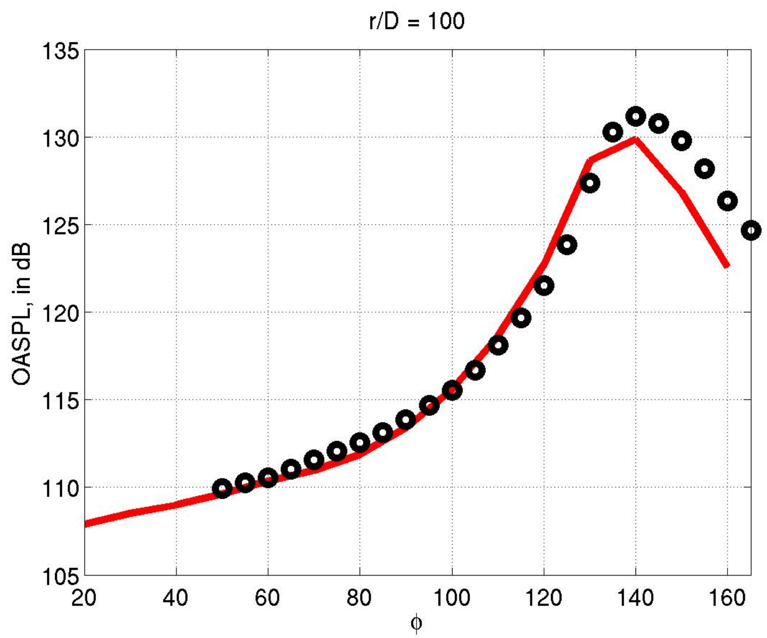
centerline turbulence intensity

Large-Eddy Simulation Research

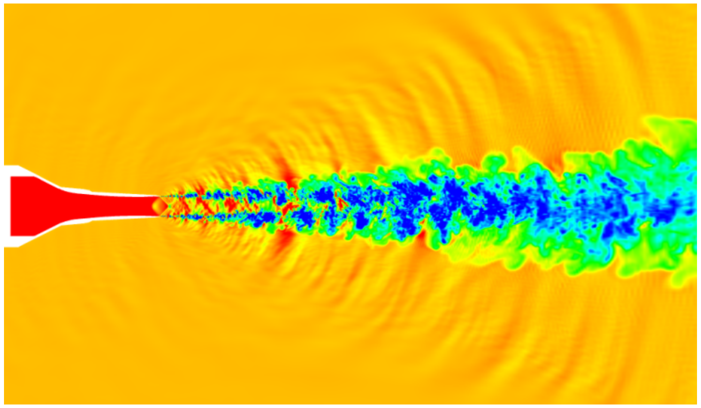
NRA: Stanford University
Sanjiva Lele, PI

- Code development for time-dependent turbulent simulations of flowfields from noise suppressing nozzles
- CDP Code
  - Unstructured
  - 2nd order energy conserving flow solver
  - Dynamic Smagorinsky sub-grid model
- Ffwocs-Williams Hawkings solver for acoustic far field

Mach 1.4 Heated Jet



OASPL at 100 diameters



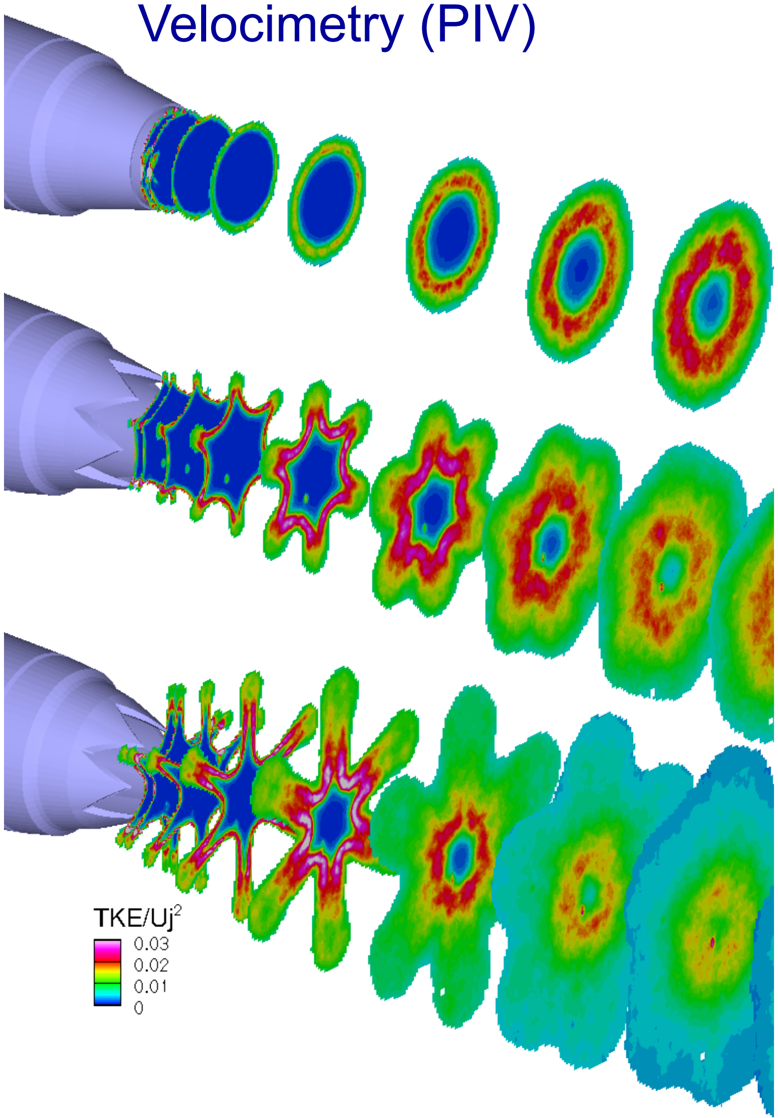
density contours

Diagnostics

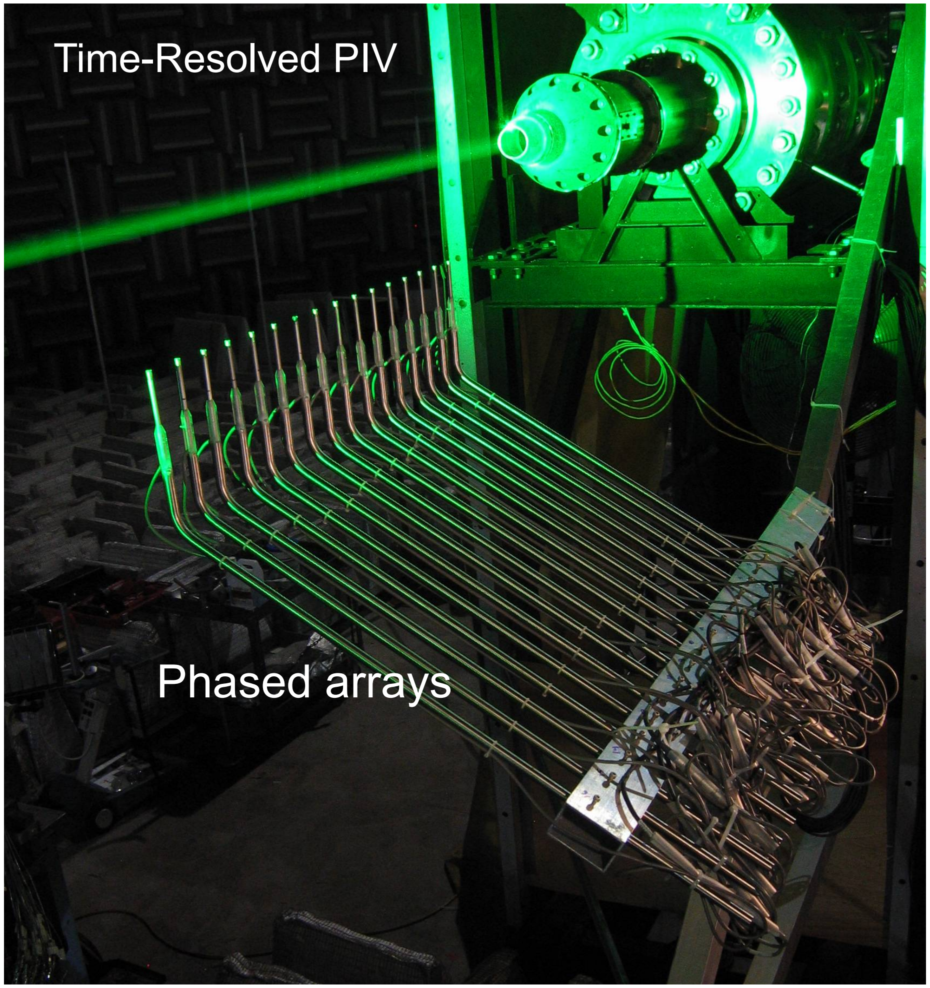
Advances in Flow Diagnostics for Noise Reduction and Prediction

James Bridges: james.e.bridges@nasa.gov

Turbulence measured in hot jets using Particle Image Velocimetry (PIV)

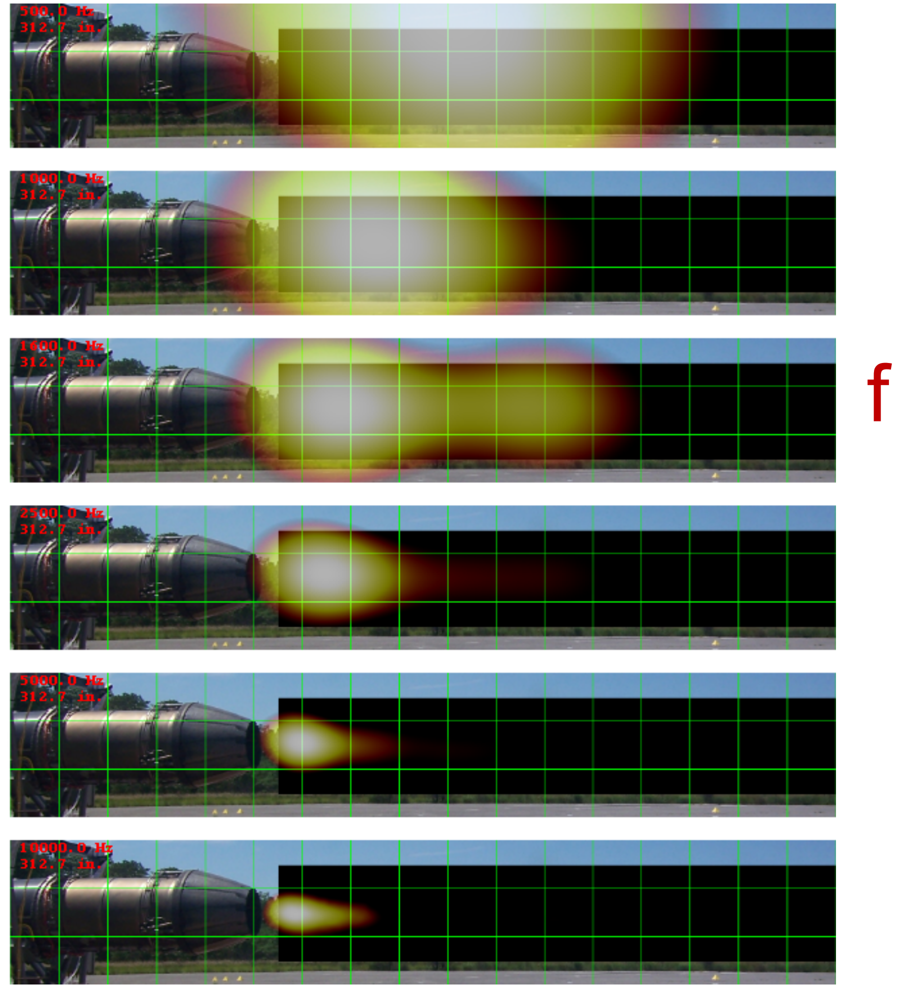


Flow-Source correlations explored using multiple advanced techniques



NAVAIR Lakehurst Test (July, 2009) – F404

Gary Podboy: gary.g.podboy@nasa.gov

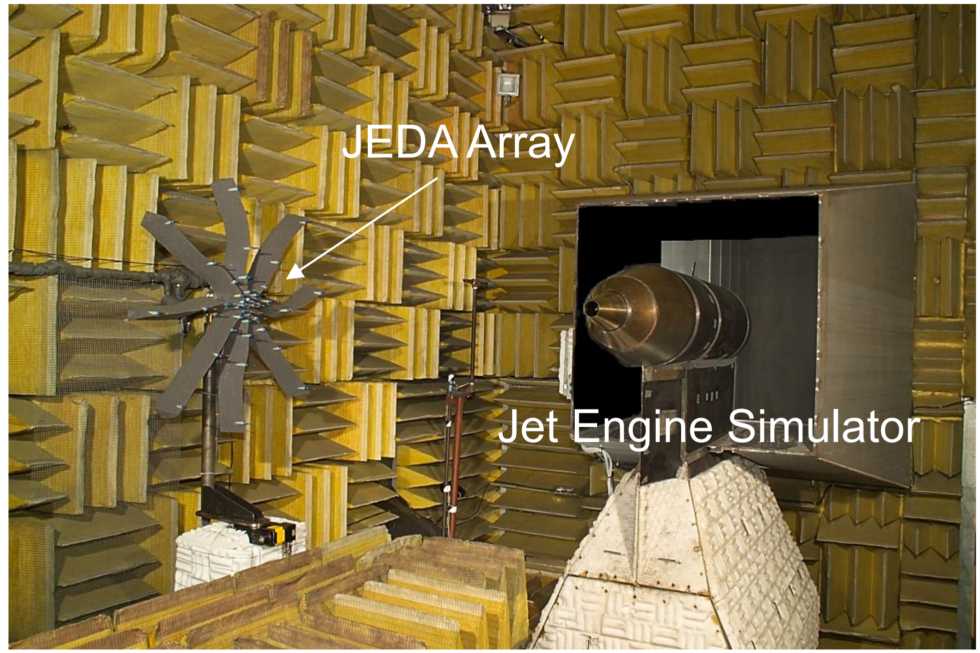


- Nozzles tested
  - Baseline
  - Chevrons designed by GE
- GE acquired near and far field data
- NASA acquired phased array data

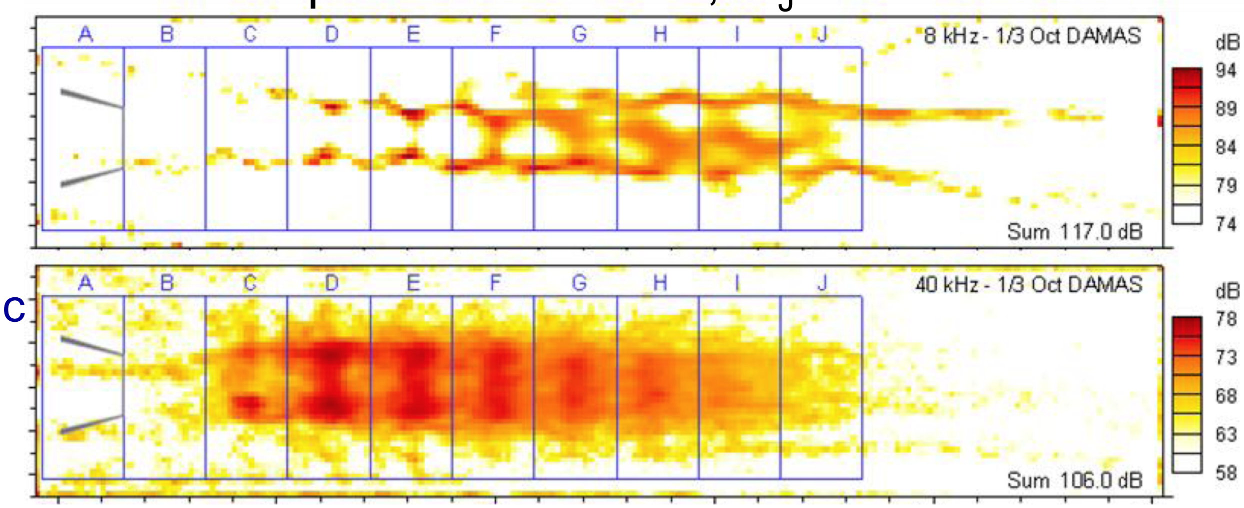
Phased Array Development for Jet Noise

Tom Brooks: thomas.f.brooks@nasa.gov

- Comprehensive jet noise data set
  - Single and dual streams
  - Heated and cold
  - Chevron and round nozzles
  - Static and simulated forward flight conditions
  - Subsonic and supersonic exhausts
- NASA developed processing method
  - DAMAS - Deconvolution approach for mapping of acoustic sources



Supersonic Cold Jet, $M_J = 1.48$



Reduction Concepts

Supersonic Jet Noise Suppression Using Plasma Actuators

NRA: The Ohio State University
PI: Mo Samimy

- Various jet instabilities are manipulated to mitigate noise
- Large Eddy Simulations used to predict optimal jet forcing for noise mitigation
- Optimized jet forcing to be tested experimentally at multiple scales

Example of actuation effects on the jet flow field

Image of baseline Mach 1.3 jet

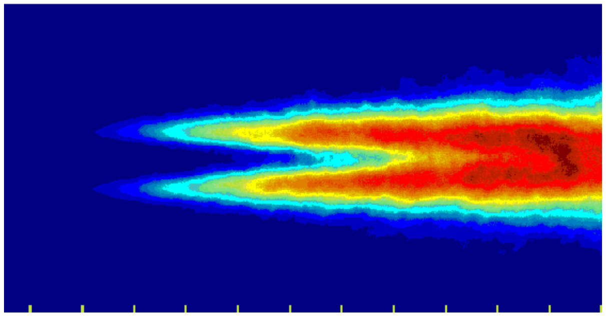
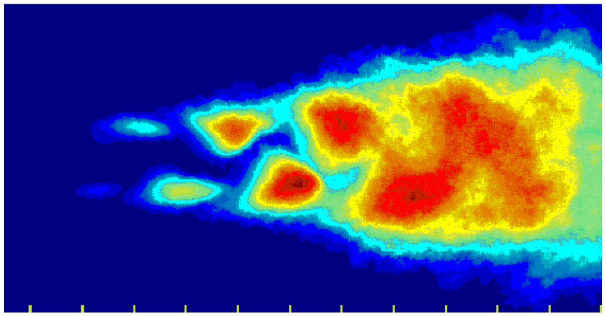
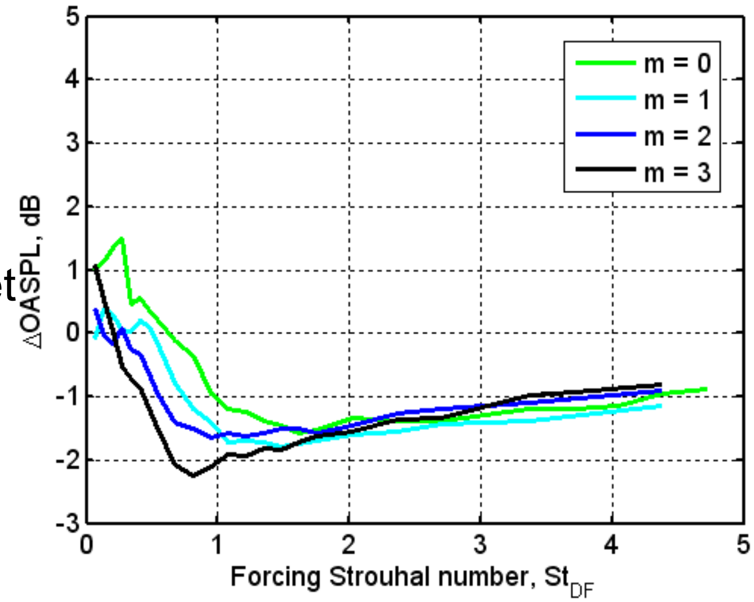


Image of forced jet at 5 kHz and at azimuthal mode m=±1



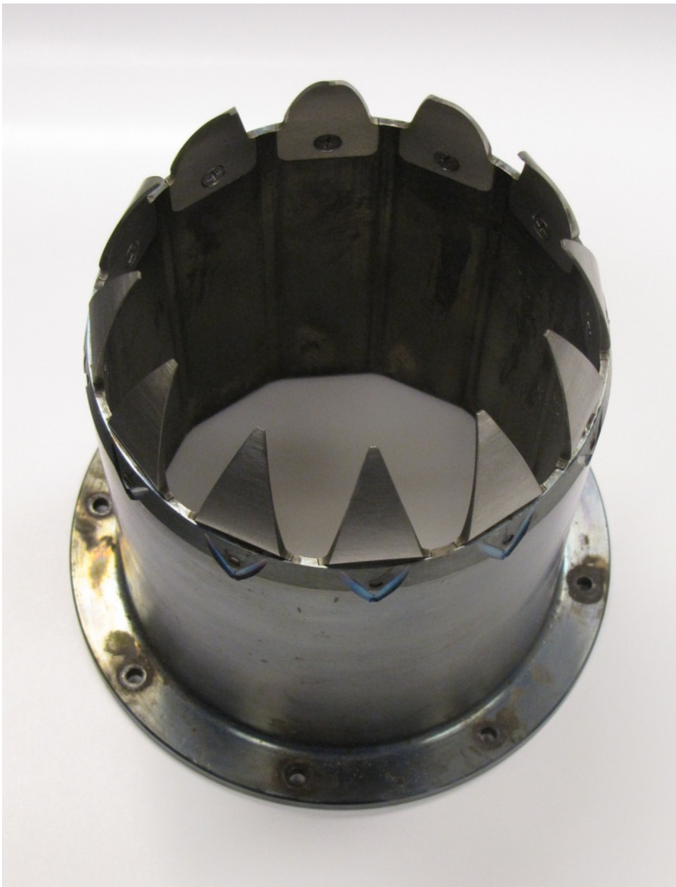
Example of noise mitigation at Mach 1.3

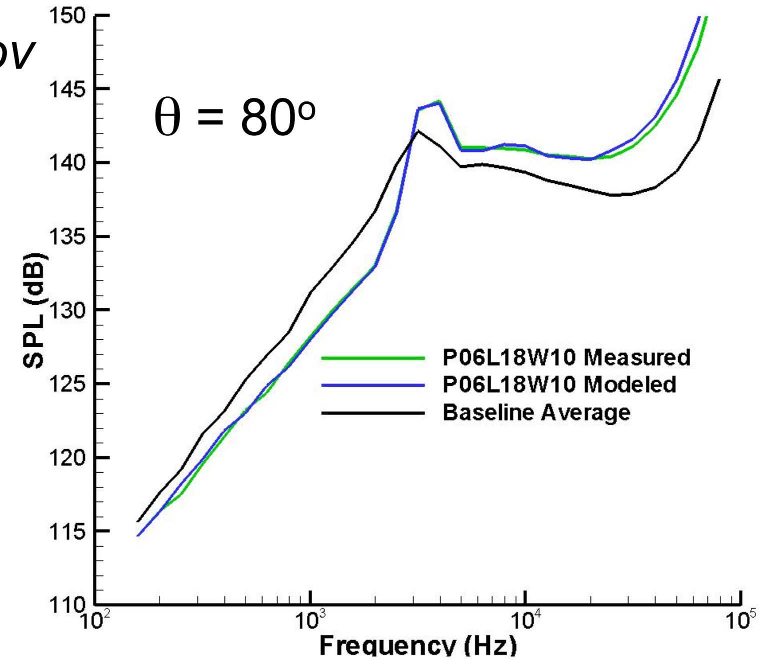
Noise reduction relative to baseline jet (actuation <u>not</u> optimized)

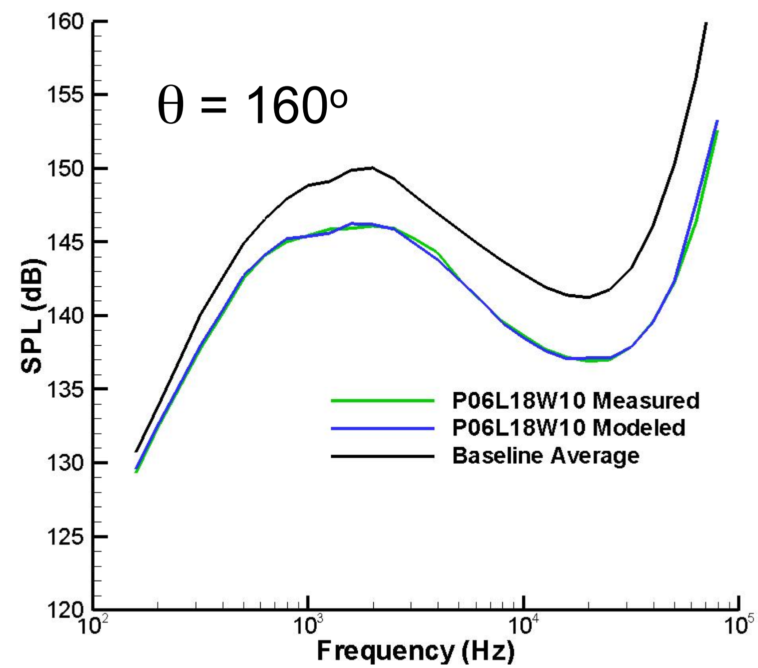


Chevrons for Overexpanded Supersonic Jets

Brenda Henderson: brenda.s.henderson@nasa.gov
James Bridges: james.e.bridges@nasa.gov

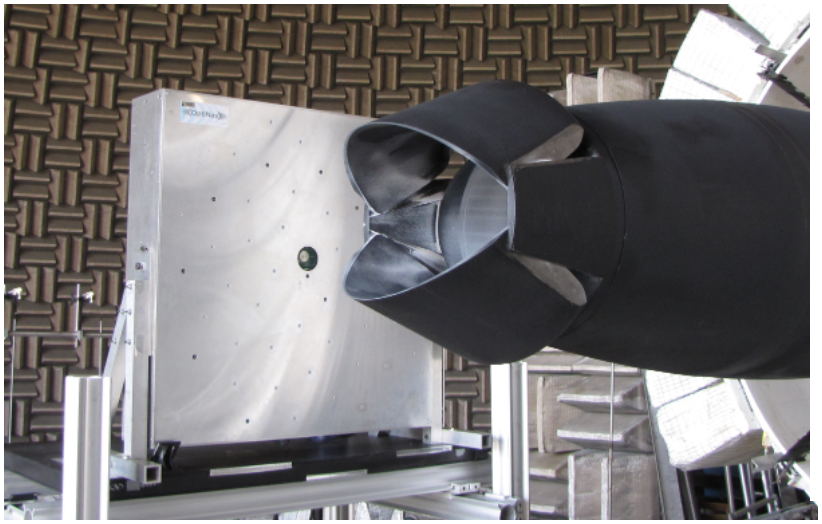


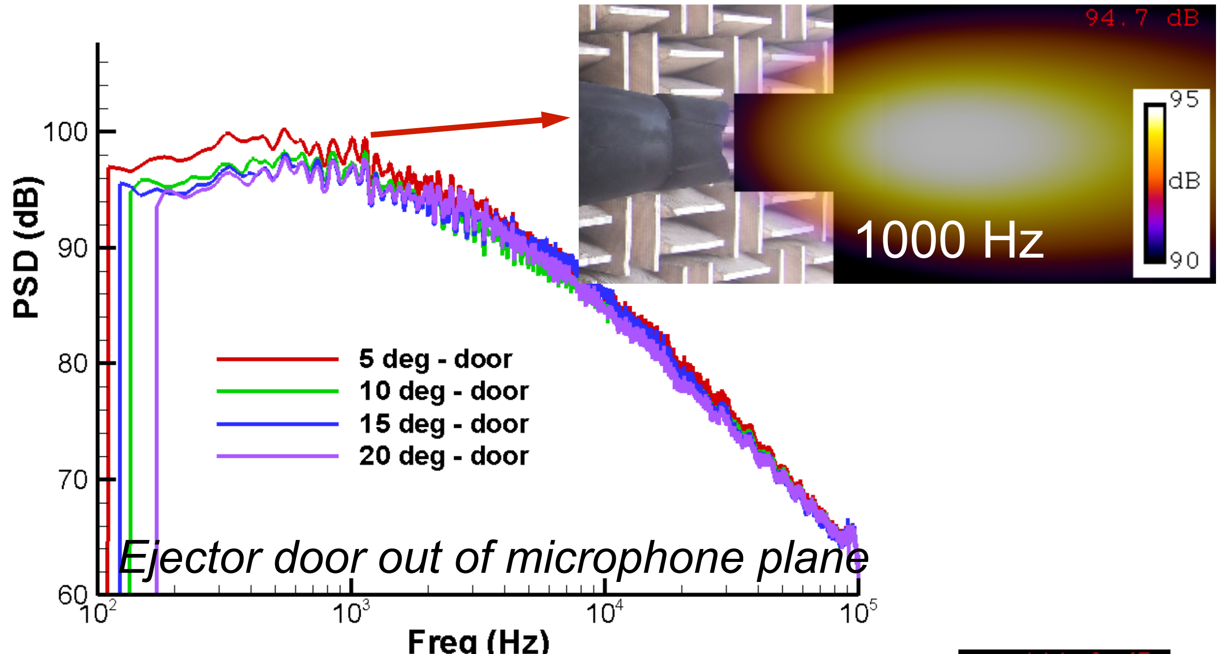




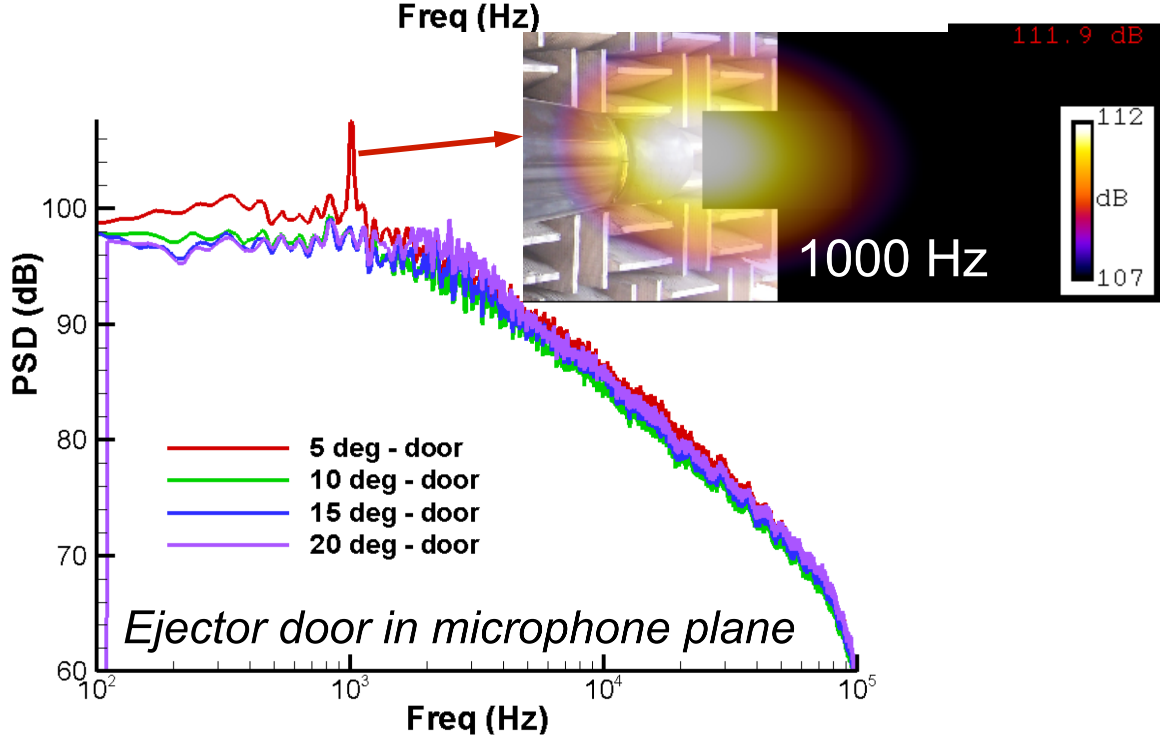
Ejectors for High Subsonic Noise Reduction

Brenda Henderson:
brenda.s.henderson@nasa.gov



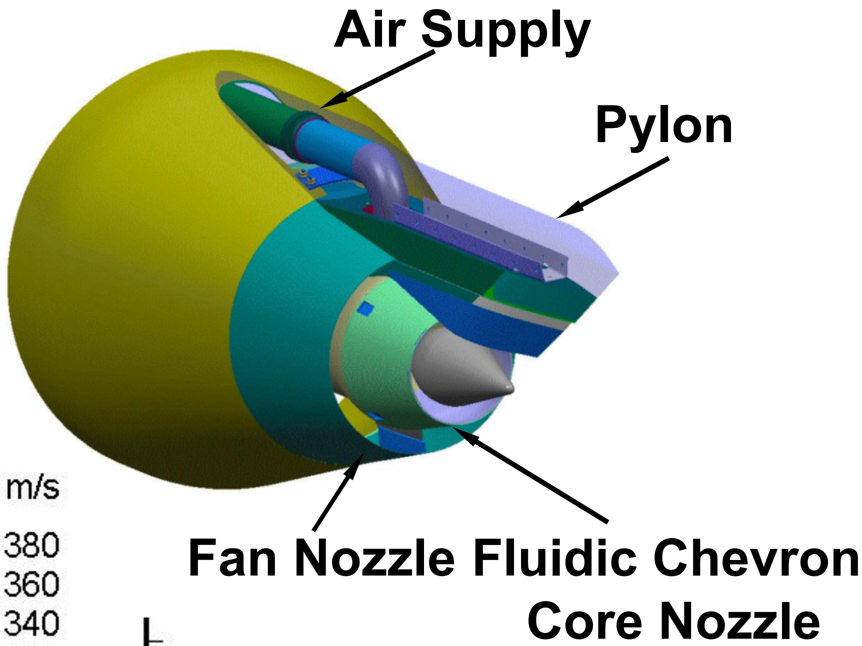


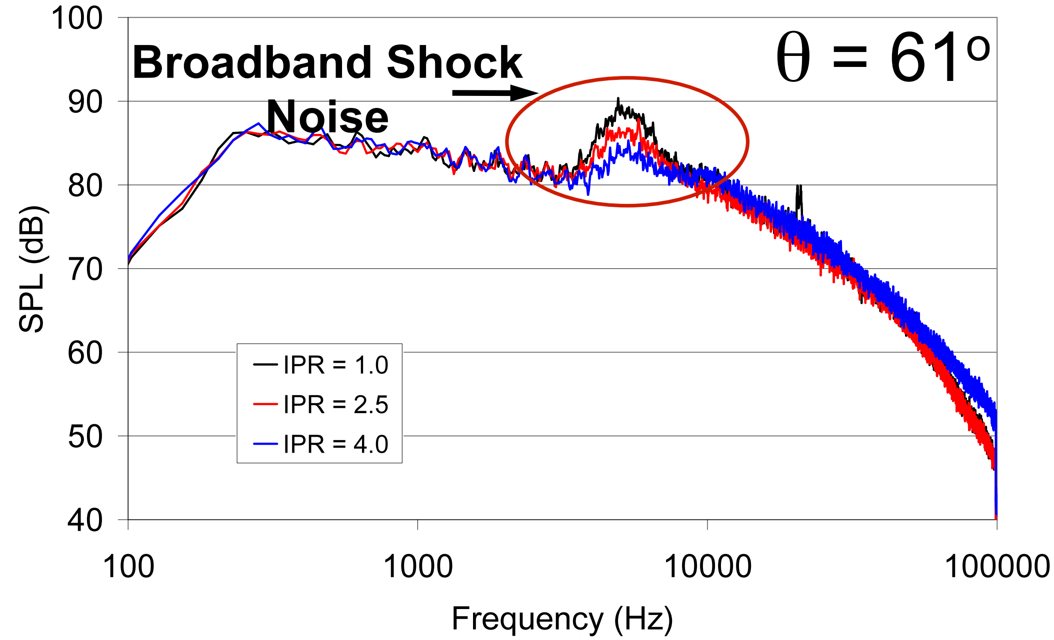
Representative Takeoff Condition
θ = 60^o

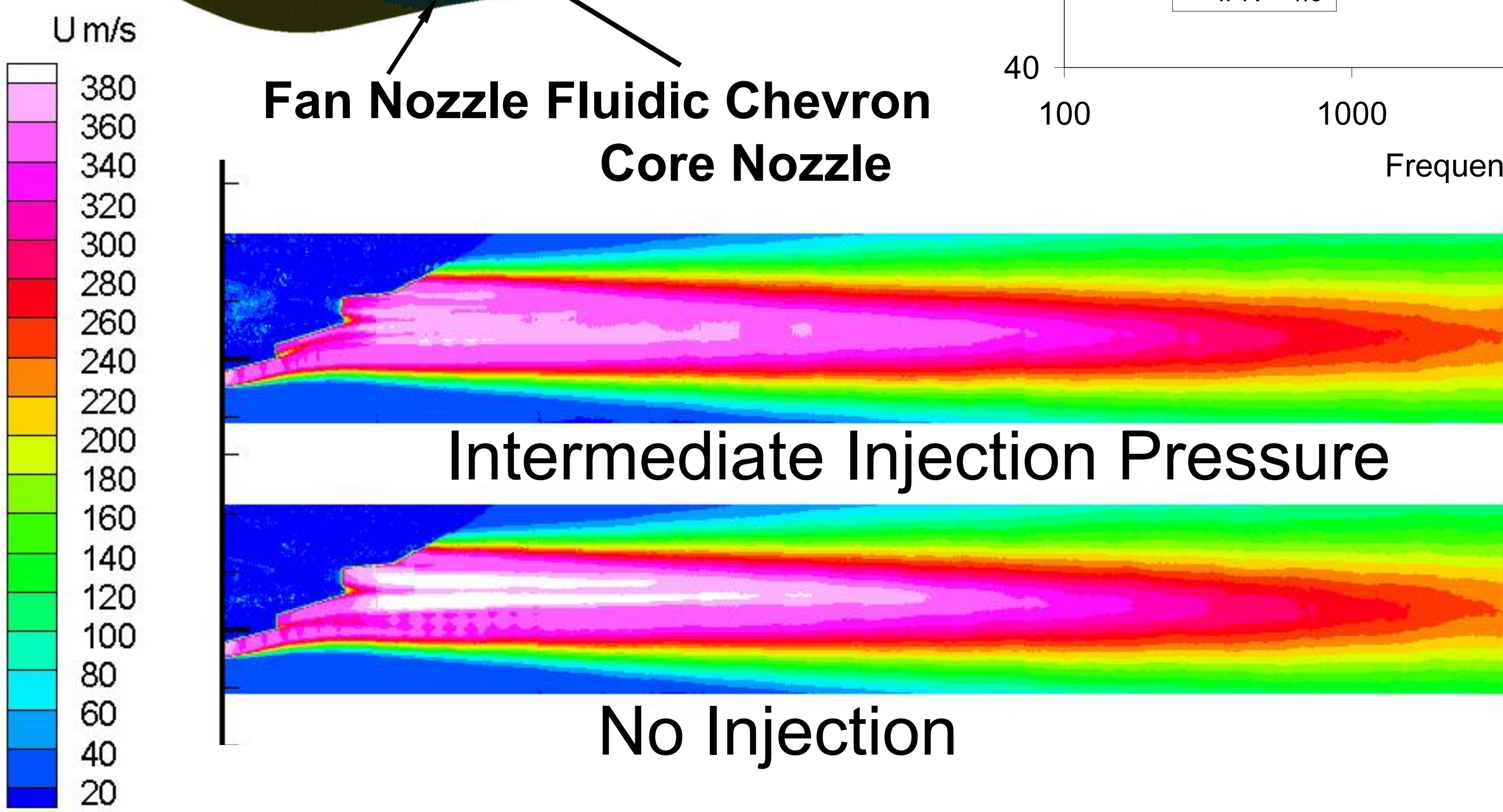


Air Injection for Supersonic Jets

Brenda Henderson: brenda.s.henderson@nasa.gov





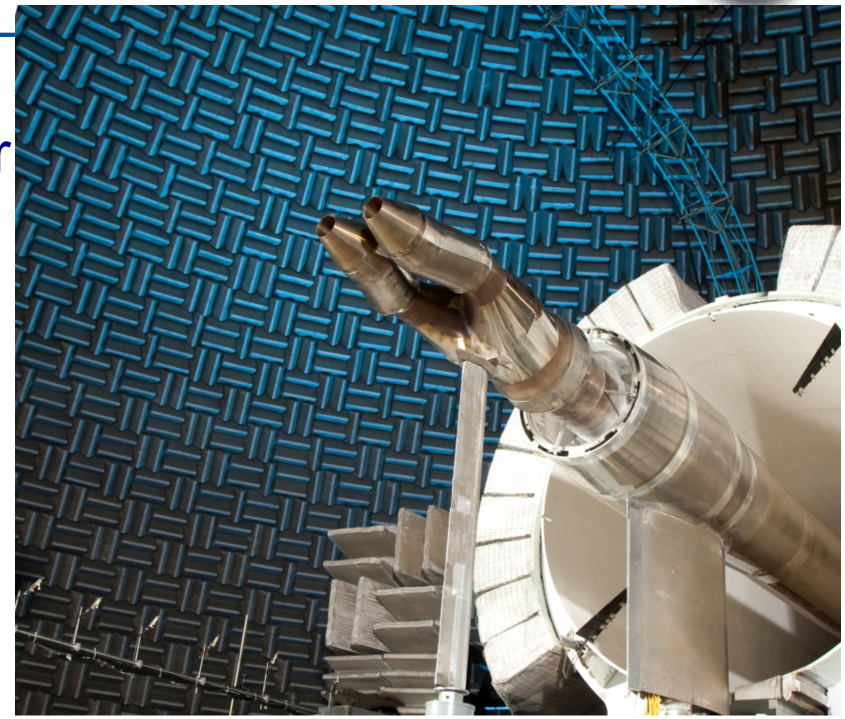


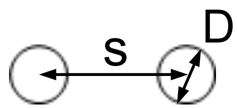
$NPR_c = 1.61$
$NPR_f = 2.23$
Hot Core

Twin Jet Investigations

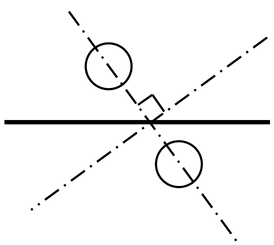
Rick Bozak: richard.f.bozak@nasa.gov

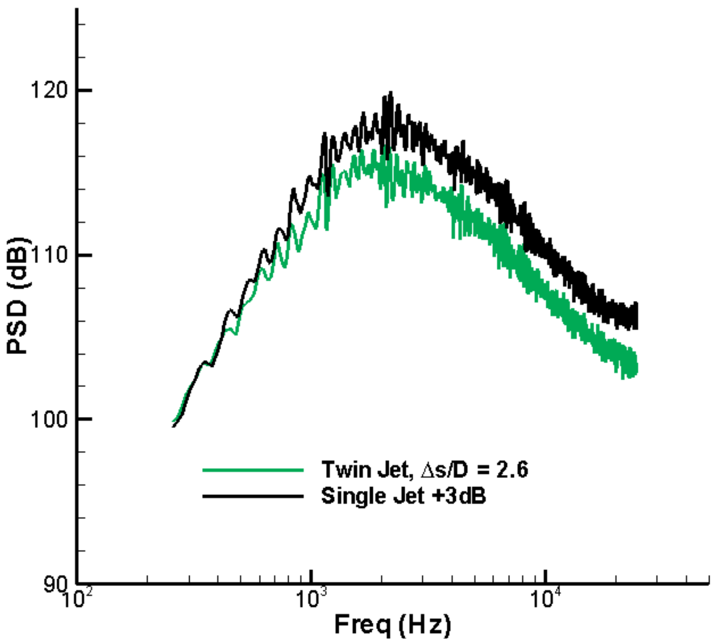
- Mapped sound field over spherical domain for multiple jet spacings (Δs/D from 2.6 to 5.5)
- Investigation included
  - Subsonic jets
  - Ideally expanded supersonic jets
  - Over and under-expanded supersonic jets



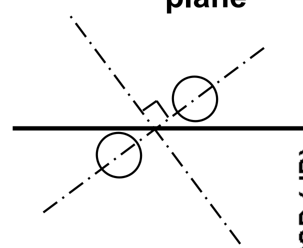


- **In-plane**

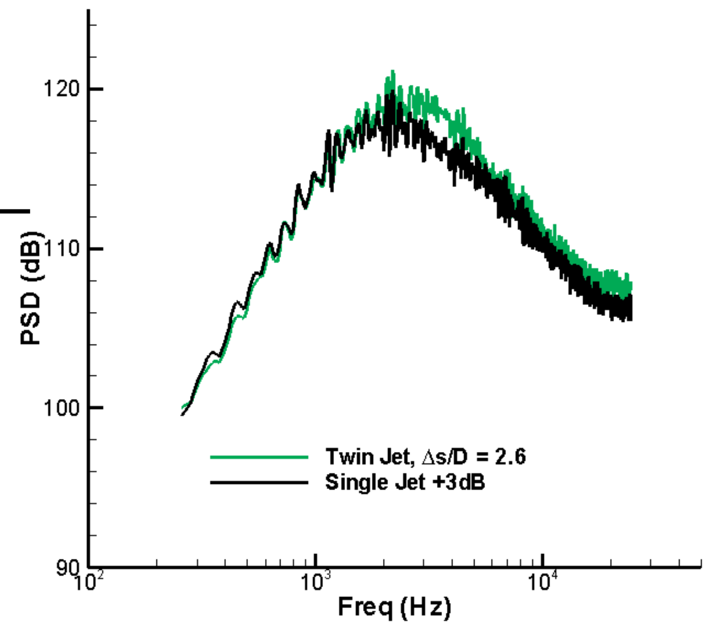




- **Out-of-plane**

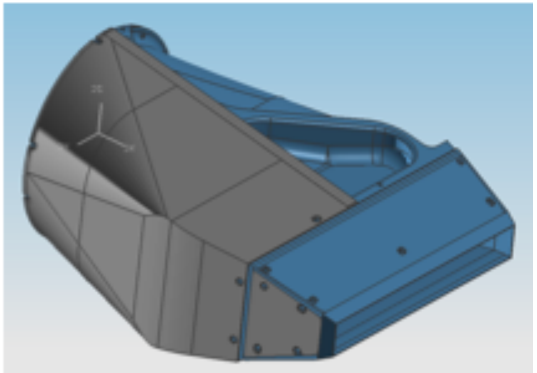


NPR=3.0
TTR=3.0
Θ = 130°

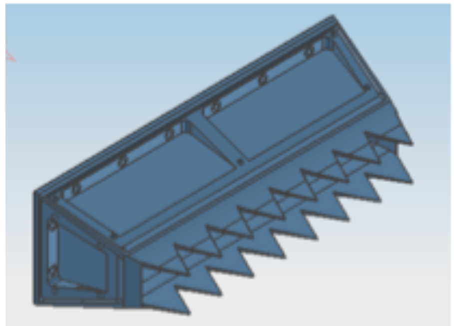


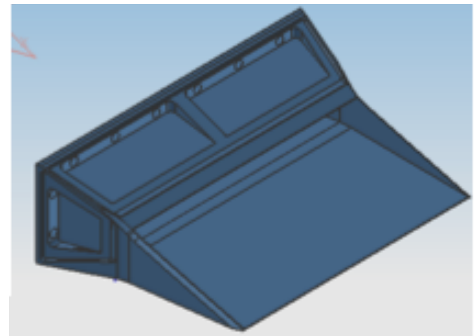
Engineering: Evolution of 2D Nozzles

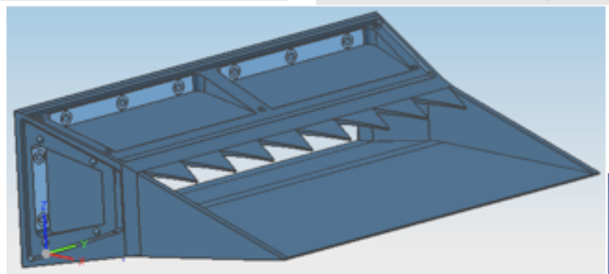
Franco Frate: franco.c.frate@nasa.gov



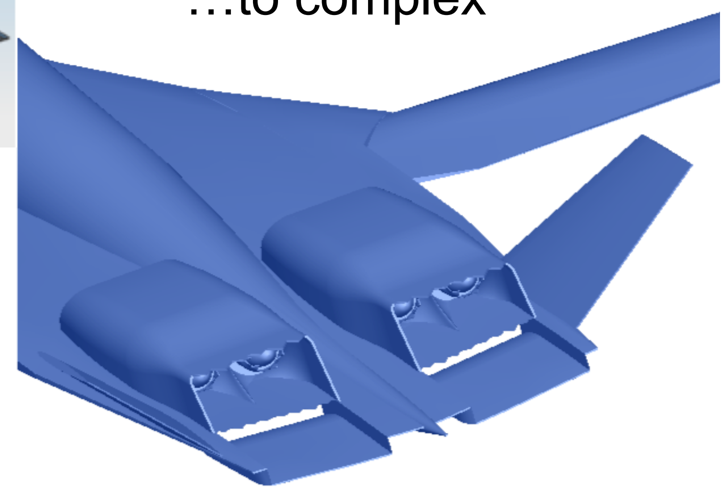
From basic…

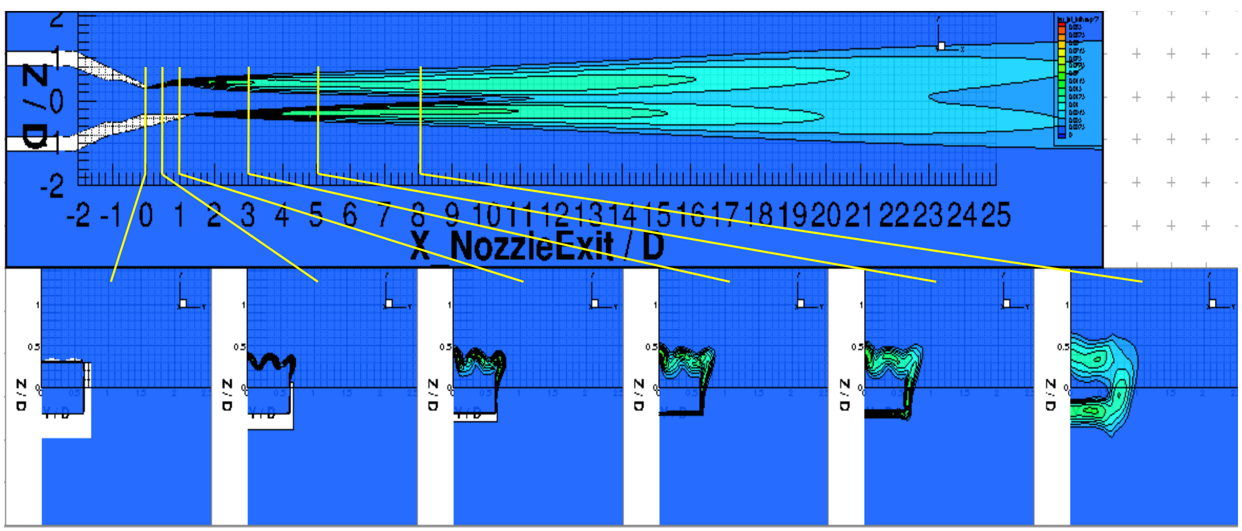






…to complex





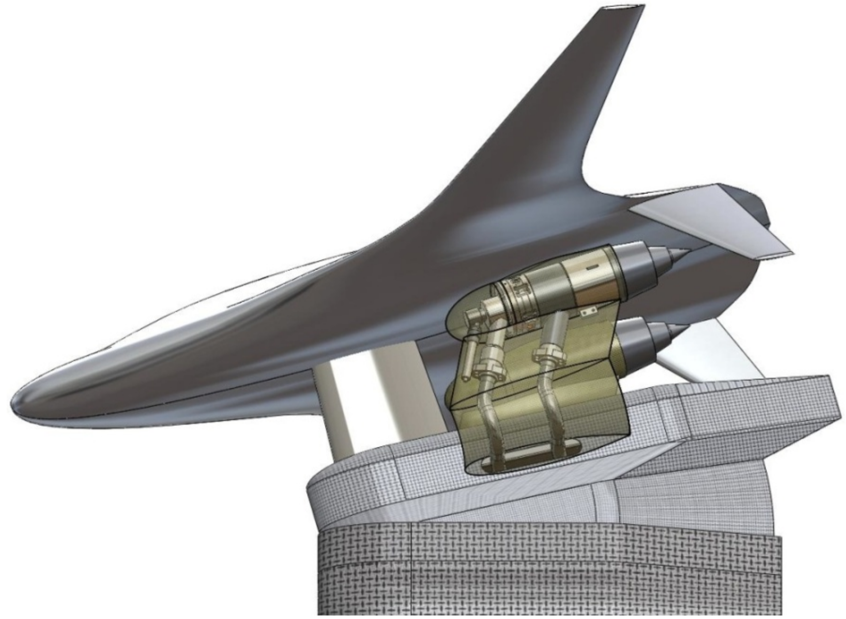
RANS-based acoustic design

Integrated Systems Research

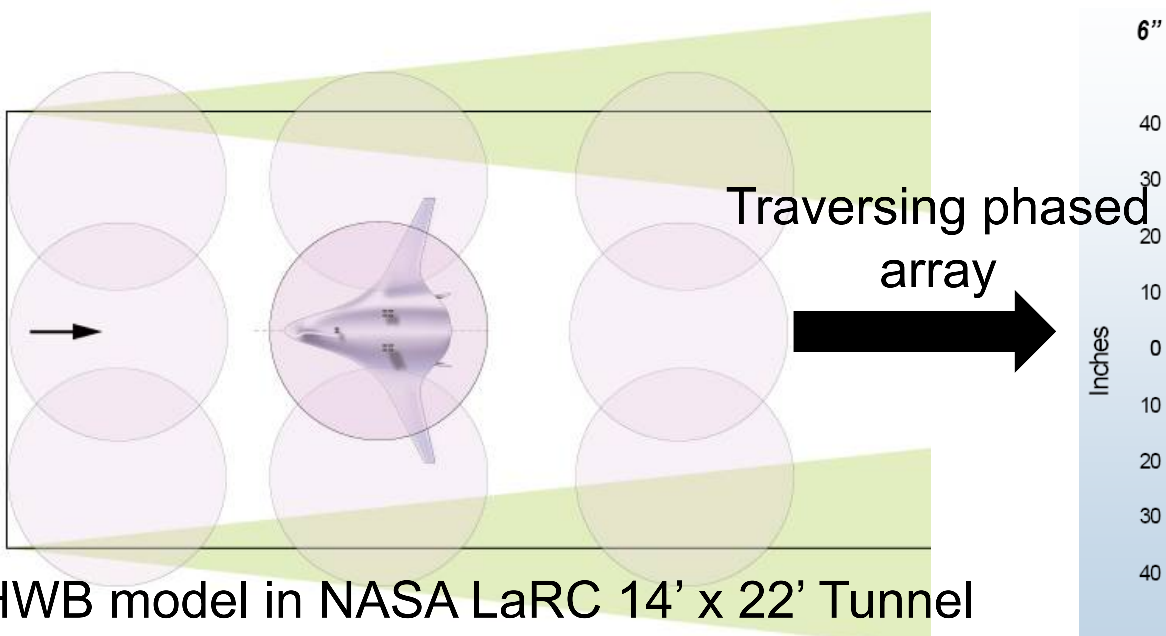
Environmentally Responsible Aviation

Hybrid Wing Body (HWB)

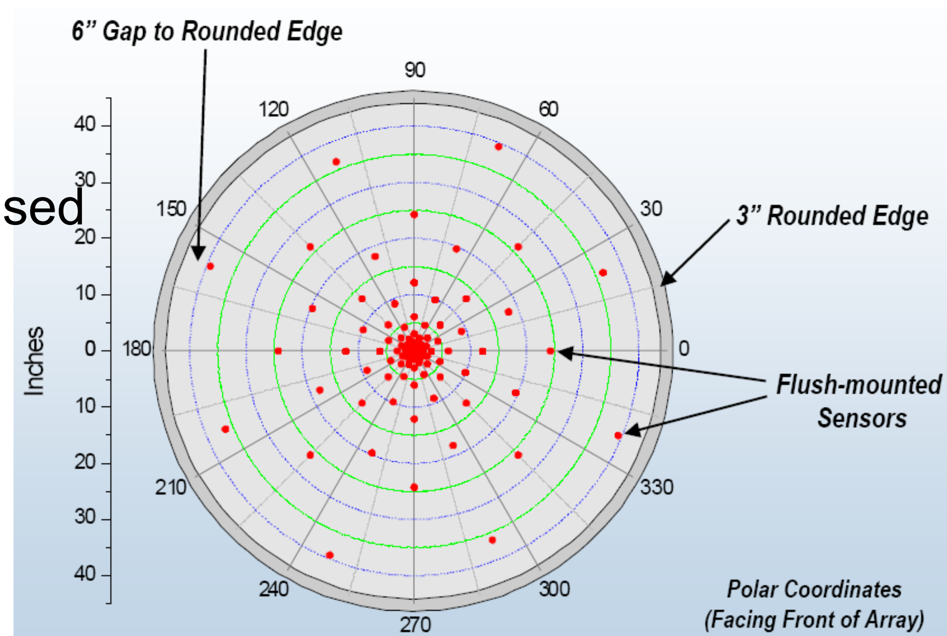
Tom Brooks: thomas.f.brooks@nasa.gov



- Test scheduled for 2012
- Two dual-stream jet engine simulators with hot flow capabilities
- Study used to characterize jet noise shielding, fan noise, and airframe noise

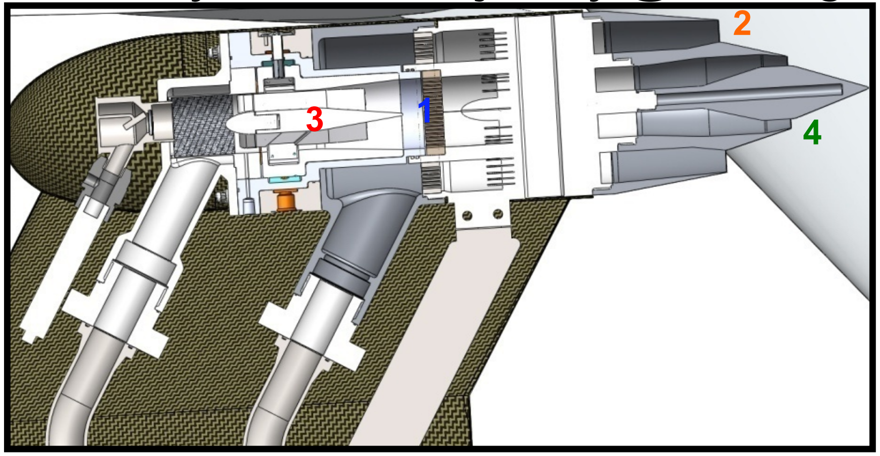


HWB model in NASA LaRC 14' x 22' Tunnel



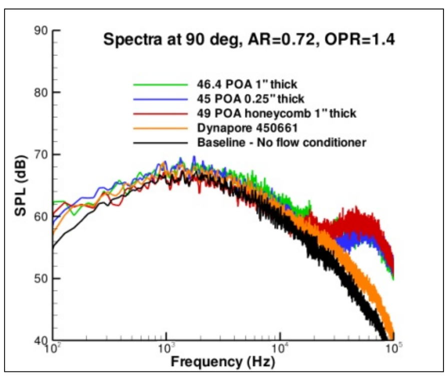
HWB Jet Noise Activities

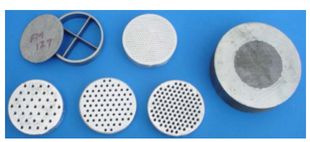
Mike Doty: michael.j.doty@nasa.gov



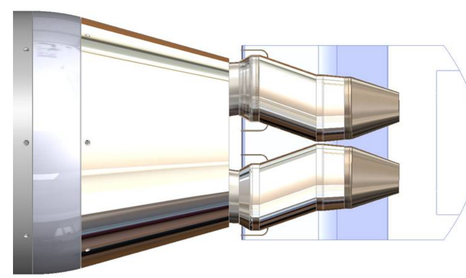
- Ongoing risk reduction and support efforts for the two Compact Jet Engine Simulators to be used in HWB model testing

1) Flow conditioner study for rig noise reduction



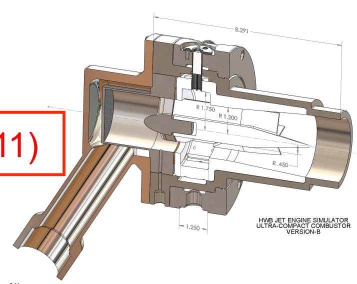


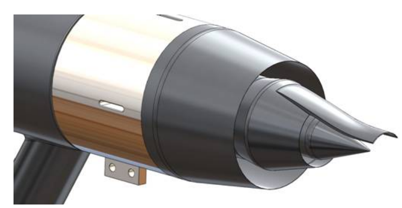
2) Shielded twin jets and acoustic source location



4) Optimum low noise nozzles for HWB shielded configuration

3) Ultra compact combustor checkout (2011)





Developing Technology Summary

- Fundamental Aeronautics Program (SFW, SUP)
  - Prediction
    - ANOPP
    - Statistical methods
      - JeNo
      - RISN
      - Other acoustic analogy based approaches
    - Time resolved methods
      - LES
  - Diagnostics
    - PIV & time-resolved PIV
    - Phased arrays
  - Noise Reduction
    - Plasma actuators
    - Ejectors
    - Air injection
    - Twin jet interaction studies
    - 2D nozzles
    - Chevrons
- Integrated Systems Research Program
  - Hybrid Wing Subsonic Transport